Collisional processing of comet surfaces: impact experiments into olivine

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Abstract

A new paradigm has emerged where 3.9 Ga ago, a violent reshuffling reshaped the placement of small bodies in the solar system (the Nice model). Surface properties of these objects may have been affected by collisions caused by this event, and by collisions with other small bodies since their emplacement. In addition, objects in the Kuiper Belt are believed to undergo extensive collisional processing while in the Kuiper Belt. Physical manifestations of shock effects (e.g., planar dislocations) in minerals typically found in comets will be correlated with spectral changes (e.g. reddening, loss and shift of peaks, new signatures) to allow astronomers to better understand geophysical impact processing that has occurred on small bodies. Targets will include solid and granular olivine (forsterite), impacted over a range of impact speeds with the Experimental Impact Laboratory at NASA JSC. Analyses include quantification of the dependence of the spectral changes with respect to impact speed, texture of the target, and temperature.

1. Introduction

The Nice model describes that during the Late Heavy Bombardment, originating from the Kuiper Belt, (a) Trojan asteroids were captured into the L4 and L5 LaGrangian points by Jupiter, and (b) comets were implanted into the outer main asteroid belt [1], [5], [6]. To match the size frequency distribution of the main belt comets, 90% of the captured objects were ground away by impacts, thus main belt comet properties may have been significantly modified by impacts. In contrast, Trojans are not theorized to have been collisionally ground down since emplacement.

Comets (r ~ 1km) residing in the Kuiper Belt will experience hundreds of impacts, and an average Kuiper Belt Object (KBO) 100 km in radius will undergo ~1 million collisions by ~4m projectiles; KBOs also undergo ~10-50 with cometary impactors 1 km in radius [3], [7]. In fact, it has been proposed that most short-period comets from the Kuiper Belt (90%) are collisional fragments from larger KBOs that are collisionally processed both on their surfaces as well as in their interiors [2]. Impacts are potential effective agents of shock metamorphism in and "gardeners" of KBO regoliths. Over 4.5 Gy, cumulative effects will process the surface and induce spectral changes in KBOs, main belt comets, and Trojan asteroids.

Two forsterite dust grains from Comet Wild 2 collected by Stardust show evidence of high density planar dislocations, 1-2 x 10^{10} cm^{-2} and one pyroxene grain exhibits microstructures that are attributed to shock effects [4], [8]. Tomeoka *et al* [8] state that shock pressures imparted by the aerogel capture process (<1GPa) are significantly lower than the pressures needed (>27 GPa) to sustain the damage evident in forsterite, and therefore propose *the damage occurred by hypervelocity impacts* before aerogel capture. By deriving an extensive set of laboratory experiments and comparing the results to Stardust and to Spitzer spectra, it will be assessed whether the heretofore unexplained difference between Trojan asteroid spectra and comets, as well as Stardust grains showing evidence of shock, can be attributed to their collisional and dynamical history.

2. Experiments

This study is developed from a suite of impact experiments performed in the Experimental Impact Laboratory (EIL) at Johnson Space Center in Houston, TX using the vertical gun. Targets included whole (solid) and granular forsterite minerals. Forsterite is (a) the most common silicate found in comet dust, and (b) has strong signatures in the 8 - 13 μm region, where observational astronomers

commonly search for cometary dust signatures. Targets were impacted with ceramic (aluminium oxide, $\rho \sim 3.6$ g cm^{-3}), chosen to simulate impacts of rocky meteoroid impactors. Targets were impacted at a range of temperatures (-196C to +25C) and impact velocities (2.2 – 3.0 km s^{-1}).

3. Analysis

Impacted targets were analyzed with a Fourier Transform Infrared Spectrometer (FTIR). This allows us to investigate the near-IR to mid-IR (1.5 – 15 μm), the wavelength range typically observed using ground-based telescopes. In addition, a subset of targets was analyzed using a Transmission Electron Microscope (TEM) to search for evidence of shock-induced alterations within the individual mineral grains. These experiments will help to establish how the mineralogy of comet dust could be influenced by collisions and will be directly compared with Stardust grains exhibiting shock effects.

4. Summary and Conclusions

We will present a suite of experiments that was conducted with solid and granular forsterite targets. These were impacted at a range of velocities and at different temperatures using the vertical gun. Targets were analyzed with an FTIR to investigate changes in spectral features for future interpretation of telescopic spectra of cometary dust, and with TEM to understand the physical manifestations of shock that correlate with spectral changes.

Initial results indicate that spectra of forsterite impacted at lower velocities (~2.0 km s^{-1}) do not exhibit any alterations in their spectra. At higher velocities, the sharp features observed in the 8-13 μm region are slightly shifted, and the band depths greatly diminished. All impacted targets were ground to ≤1 μm for analysis with the FTIR and TEM, so size does not explain the spectral effects. Rather, they can be explained by dislocations in the crystal structure diminishing the transmittance of light.

TEM images clearly demonstrate evidence of high planar dislocations (on the order of 10^{10} cm^{-2}), similar to that seen in olivine grains of Comet Wild 2, collected by the Stardust spacecraft. This supports the hypothesis that comets have undergone collisional evolution since formation.

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